SECTION 8
BALLAST WATER MANAGEMENT SYSTEM PERFORMANCE

The performance of BWMS is important in determining appropriate ballast water discharge limitations for the VGP. EPA compiled and reviewed available BWMS performance data from USCG type approval testing, submittals to the USCG for Alternate Management System (AMS) acceptance, and reports submitted to Administrations for the type approval of BWMS in accordance with MEPC resolution MEPC.125(53) and MEPC.174(58) *Guidelines for Approval of Ballast Water Management Systems* (G8). The requirements for BWMS testing have evolved over time to become more specific. Therefore, the quality of performance data has changed. BWMS approval processes, EPA's methodology for evaluating BWMS performance and data quality, and EPA's findings of are described in this section.

8.1 IMO AND USCG TYPE APPROVAL REQUIREMENTS

The 2013 VGP requires vessels covered by the VGP to achieve the ballast water discharge limits in VGP Part 2.2.3.5 using one of four ballast water management measures provided in Part 2.2.3.5.1 and in accordance with the implementation schedule in Part 2.2.3.5.2. If a vessel uses a BWMS[1] to comply with the VGP discharge limits, the BWMS must be either type approved by the U.S. Coast Guard (USCG) under 46 CFR § 162.060 or have received Alternative Management System (AMS) acceptance by the USCG under 33 CFR § 151.2026[2].

The USCG type-approval testing procedures are mandatory, detailed, and require that testing be conducted by a USCG accepted independent laboratory (IL) that is independent of the BWMS manufacturer. The IL oversees and conducts all the required testing and generates a report with the details recommending type approval. A BWMS is eligible for type approval by the USCG if:

- It meets the design and construction requirements in 46 CFR § 162.060–20,
- It is evaluated, inspected, and tested under land-based and shipboard conditions in accordance with 46 CFR §§ 162.060–26 and 162.060–28 by an IL to demonstrate the ballast water discharge standard in 33 CFR Part 151 Subparts C and D are consistently achieved,
- Applicable components of the BWMS meet the component testing requirements of 46 CFR § 162.060–30, and
- The ballast water and any active substance or preparation used in the BWMS are not found to be persistent, bioaccumulative, or toxic when discharged.

After receipt of the type approval documentation by the IL, the USCG Marine Safety Center evaluates the report and determines if USCG type approval should be awarded. The

[1] The VGP references ballast water treatment systems (BWTS), but the USCG and the international community have determined to use the uniform terminology of BWMS to alleviate any confusion.

[2] USCG ballast water discharge standards are the same as VGP discharge limitations.

overall process is estimated to require approximately two years. As of October 1, 2017, the USCG awarded type approval to five BWMS.

The process for USCG acceptance of a BWMS as an AMS is different. The USCG developed the AMS program to respond to ships that have BWMS installed that were approved according to international requirements. A USCG accepted AMS is a BWMS "approved by a foreign administration pursuant to the standards set forth in the International Maritime Organization's International BWM Convention" (33 CFR § 151.1504). The USCG has accepted over 100 BWMS as AMS as of October 2017.

The IMO Marine Environment Protection Committee (MEPC) established guidelines for type approval of BWMS with Administrations (i.e., countries) responsible for type approval of BWMS on ships under their flag. G8 was initially adopted at MEPC 53 in MEPC Resolution MEPC.125(53), subsequently revoked by MEPC Resolution MEPC.174(58), and more recently revised by MEPC Resolution MEPC.207(70). Most BWMS are type approved according to MEPC.174(58). The recommendatory guidelines are applied differently by flag administrations and do not require testing to be conducted by an organization independent of the manufacturer. The G8 Guidelines provide general guidance on:

- The general technical specifications for treatment and control and monitoring equipment,
- Documentation requirements,
- Approval and certification procedures,
- Pre-test evaluation of documentation,
- Test and performance specifications for BWMS,
- Environmental testing specifications for BWMS, and
- Sample analysis methods for the biological constituents to be tested.

In October 2016, MEPC 71 agreed to make the recently revised Guidelines G8 (MEPC.279(70)) a mandatory code to be amended to the BWM Convention after entry into force. MEPC 70 suggested that Administrations no longer approve BWMS to the previous G8 (MEPC.174(58)) after 28 October 2018 and agreed that all BWMS installed onboard ships would need to be approved by the newly revised G8 (MEPC.207(70)) on or after 28 October 2020.

8.2 EXISTING BWMS PERFORMANCE DATA REVIEWS

As a first step in evaluating BWMS performance, EPA identified and reviewed existing BWMS performance data reviews. BWMS performance has been reported by the U.S. EPA Science Advisory Board, the California State Lands Commission Marine Invasive Species Program, and the U.S. Naval Research Laboratory.

8.2.1 U.S. EPA Science Advisory Board (SAB)

The USEPA SAB initially published a report in 2011 titled *Efficacy of Ballast Water Treatment Systems: a Report by the EPA Science Advisory Board* that responded to the EPA's

Office of Water (OW) request to "provide advice on technologies and systems to minimize the impacts of invasive species in vessel ballast water discharge" (USEPA, 2011). The SAB was to advise on "the effectiveness of existing technologies for shipboard treatment of vessel ballast water, how these technologies might be improved in the future, and how to overcome limitations in existing data."

To perform this assessment, the panel first reviewed available reports (Albert et al, 2010; CSLC, 2010; Lloyds, 2010) to identify 51 BWMS that were commercially available or in-development at the time of the assessment. Of these 51 BWMS, the SAB had data packages for 15 BWMS. The type, amount, and quality of material in the data packages varied, ranging from only a type approval certificate to land-based and shipboard testing methods and data. The SAB panel described limitations of the data packages, test protocols, and results:

- Packages lacked detailed information, including documentation of test protocols and whether they were followed, full reporting of all results and raw data (i.e., reporting of both successful and failure test results), and documentation of QA/QC procedures and whether they were followed.

- The G8 guidelines used for BWMS performance testing provide only general recommendations for how to evaluate performance with respect to the D-2 standards. Accordingly, test protocols across BWMS were inconsistent and may lack rigorous statistical sampling protocols (issues with sample size, volume, replicates) and subsequent statistical analysis necessary to assess BWMS performance.

- Lack of documentation regarding whether the BWMS was in operational use (i.e., used onboard vessels on one or more active ships operating throughout the range of environmental conditions encountered, vessel operational parameters, and vessel design characteristics).

Next, three subgroup members independently reviewed each of the data packages to determine whether they contained "reliable data" sufficient to permit a "credible assessment" of performance capabilities. To receive a reliable rating, the data package had to include, at a minimum, methods and results from land-based or shipboard testing. Members also assessed other criteria, such as whether the testing protocols included reasonable and appropriate methods, and whether the testing produced credible results. The panel determined that nine BWMS representing five BWMS categories had reliable data. It is important to note that when classifying data packages, the panel did not assess performance data quality. Instead, the panel made a critical assumption that all protocols and methods were followed exactly as described, regardless of the presence or absence of QA/QC procedures and documentation (USEPA, 2011). Therefore, any use of the findings of the SAB panel should consider this lack of quality assessment.

For BWMS with reliable data, the panel evaluated the systems' ability to meet the following four discharge standards: IMO D-2/USCG Phase 1, and 10x, 100x, and 1,000x more stringent than IMO D-2/USCG Phase 1. The panel found that all five BWMS categories were demonstrated to meet the IMO D-2/USCG Phase 1 standard when tested in accordance with IMO

G8 standards. The panel also found that all five BWMS categories were likely to meet the IMO D-2/USCG Phase 1 standard when tested in accordance with the ETV Protocol (USEPA, 2010); however, performance was not demonstrated as the none of the BWMS had not undergone such testing. The panel found that none of the BWMS categories were demonstrated to achieve more stringent discharge standards due to insufficient resolution of the testing methods (USEPA, 2011). Detection limits for currently available test methods preclude a complete statistical assessment of whether BWMS can meet standards more stringent than IMO D-2/USCG Phase 1. Improved testing protocols would be required to develop more stringent discharge standards (USEPA, 2011).

In 2016, the EPA SAB reviewed the conclusions of the 2011 SAB report and confirmed that the findings and conclusions were supported by the data available at that time, and that the data did not support discharge limitations exceeding the 2013 VGP discharge limitations (USEPA, 2016).

8.2.2 California State Lands Commission (CSLC) Marine Invasive Species Program

The CSLC Marine Invasive Species Program has published biennial reports on their activities from 2003 through 2015 and has performed seven assessments on the efficacy of BWMS from 2007 through 2014. California regulations require the phasing in of more stringent performance standards compared to the USCG and BWM Convention. The CSLC assessment reports focused on the ability of technologies to achieve the more stringent California requirements (see Section 2.6.1 for a description of the California requirements). While these reports provided analyses of BWMS performance, the quality of the data analyzed was not described, indicating that the commission did not assess performance data quality. Therefore, any use of the findings of the CSLC assessments should consider this lack of quality assessment.

In their most recent assessment report, CSLC noted that their standards apply to ship discharges, not the type approval of BWMS, and highlighted the lack of data from shipboard performance. Due to these issues, CSLC stated that it was "not possible to determine if shipboard treatment systems are available to meet the California performance standards based solely on existing data" (CSLC, 2014).

8.2.3 U.S. Naval Research Laboratory (NRL)

The USCG tasked the NRL to review existing BWMS performance data to determination whether testing protocols can accurately measure compliance with the ballast water discharge standard (among other objectives). NRL reviewed AMS applications for 50 BWMS having USCG AMS acceptance as of September 9, 2015. NRL's review focused on whether the provided test data included the information necessary to calculate a method detection limit (MDL) and the upper and lower confidence intervals around the mean for both the two largest size classes of organisms for both land-based and ship-based testing. BWMS test data that are insufficient to calculate the MDL and confidence intervals are inconclusive in demonstrating the capability of the BWMS to meet the discharge standards. NRL found that the AMS applications were unclear in how biological efficiency data were generated as documented procedures and records were missing, ambiguous, or in conflict. None of the BWMS evaluated provided sufficient data from which to calculate MDLs for both organism sizes for both land-based and

shipboard type approval testing. NRL acknowledges the possibility that BWMS can comply with the discharge standards; however, this capability could not be demonstrated by the available data.

8.3 PERFORMANCE DATA QUALITY ASSESSMENT

Performance data used for establishing ballast water discharge limitations must be of high quality. As discussed above, existing BWMS performance data reviews did not assess performance data quality. Therefore, EPA endeavored to conduct an independent review of BWMS performance and data quality.

EPA developed a rating system to provide a subjective means for determining whether available performance data are of acceptable quality for inclusion in EPA's BWMS performance review. The rating system considers the VGP requirements and the requirements of the USCG and BWM Convention for testing of BWMS. The basis for each of the scores in the rating system is described in Table 8-1. EPA determined that only performance data with a quality rating system score of 5 are of sufficient quality for use in evaluating BWMS performance.

Table 8-1. BWMS Performance Data Quality Rating System

Score	Score Description
5	Documents contain complete project-specific Quality Assurance Project Plan (QAPP) with details (e.g., Standard Operating Procedures (SOPs) and quality management system) on sample analysis, sample collection protocol and details of specific sampling events, including dates, sample volumes, replicates, field duplicates, BWMS flow rates and any deviations from the sampling plan. Complete data sets are available, have been independently reviewed and approved, are consistent with QAPP and SOPs, and demonstrate unambiguous, statistically significant, consistent and reliable performance of BWMS. Data are of sufficient quality for EPA's use in evaluating BWMS performance.
4	Documents reference QAPP but do not include the QAPP or no means for obtaining the QAPP. Information contains details on specific sample analysis, sample collection protocol and details of specific sampling events, including dates, sample volumes, replicates, field duplicates, BWMS flow rates and specifics about sampling event. Complete data sets are available and demonstrate consistent and reliable performance of BWMS. Data are not of sufficient quality for EPA's use in evaluating BWMS performance.
3	Documents reference QAPP but do not include the QAPP, do not provide means for obtaining the QAPP, include a generic rather than project-specific QAPP, or provide only general quality assurance (QA) and quality control (QC) measures. Information is incomplete and contains details on most, but not all, of the following: specific sample analysis and sample collection protocol and details of specific sampling events, including dates, sample volumes, replicates, field duplicates, BWMS flow rates and specifics about sampling event. Data sets are available and demonstrate performance of BWMS. Data are not of sufficient quality for EPA's use in evaluating BWMS performance.
2	Documents mention general QA/QC measures but does not include sufficient specific information on the sampling event (i.e., dates of specific sample collection, volumes, replicates). Only summary data sets are available to demonstrate performance of BWMSs. Data are not of sufficient quality for EPA's use in evaluating BWMS performance.

Table 8-1. BWMS Performance Data Quality Rating System

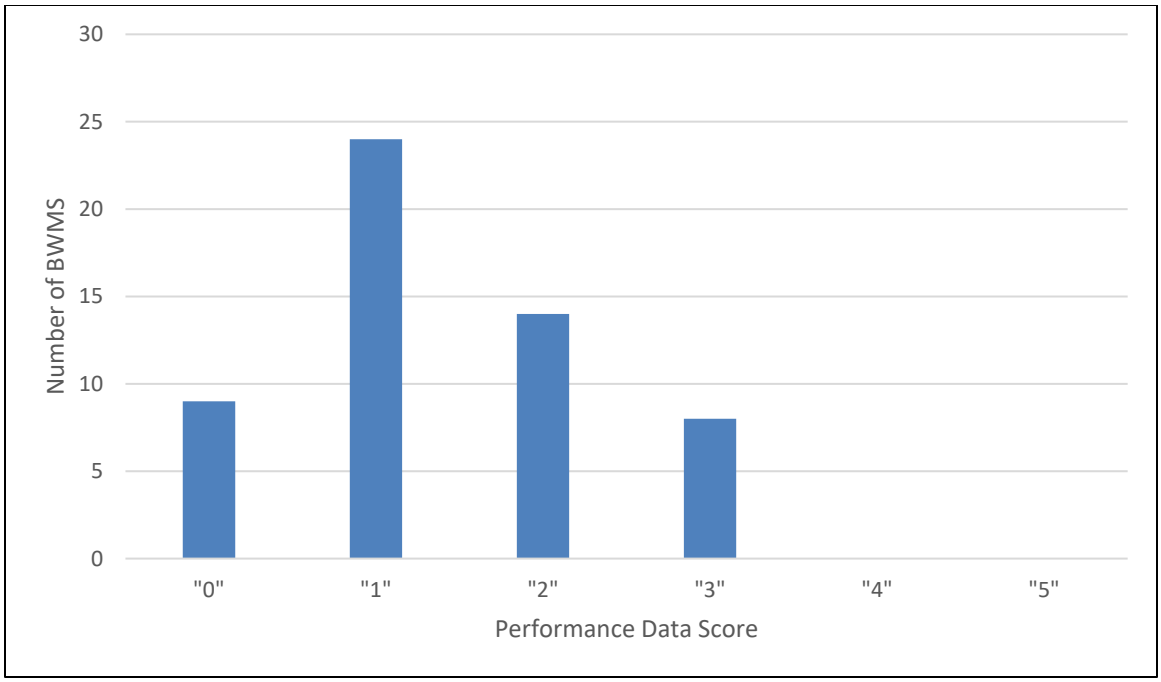
Score	Score Description
1	Documents provide general description of means for collecting samples and analysis conducted, but does not mention any test specific QA/QC measures. Information is not specific to BWMS and appears repetitive of other reports from the same laboratory. Information includes summary data or single points of data, and does not contain complete information for dates specific samples were collected, sample volumes or replicates. Data are not of sufficient quality for EPA's use in evaluating BWMS performance.
0	No description of QAPP, quality measures or details on samples collection and analysis methods. Only summaries or single points of data available. Data are not of sufficient quality for EPA's use in evaluating BWMS performance.

8.4 AMS PERFORMANCE DATA REVIEW

EPA obtained data packages for 55 BWMS submitted to the USCG for AMS acceptance. Performance testing for all 55 BWMS where all conducted in accordance with IMO G8 standards. EPA reviewed each of the data packages against the data quality criteria listed in Table 8-1 to determine whether their performance data were of acceptable quality for inclusion in EPA's BWMS performance review. EPA reviewed test reports from both land-based and shipboard testing, but focused on land-based testing to ensure specific test challenge conditions were achieved. EPA's detailed performance data quality review and findings are documented in a memorandum titled *AMS Data Quality Review* (ERG, 2017), available in the VGP docket.

Overall, performance data quality rating scores for each BWMS ranged from "0" to "3" with the median rating of "1". Figure 8-1 provides a breakdown of the performance score data. None of the data packages met EPA's data quality criteria and therefore none of the AMS performance data were included in EPA's BWMS performance review.

Most USCG AMS acceptance submittals lacked information on test-specific Quality Management Plans (QMP) and QAPP as well as individual test results. Average data results were frequently submitted without specific sample dates or reporting of the individual data results. While the quality of data improved over time, many reports did not contain sufficient information on field replicate samples used for QA/QC measures or the actual BWMS flow rate at the time of sampling. None of these BWMS performance data packages met EPA's threshold criteria for use in evaluating BWMS performance (i.e., quality rating system score of 5).



Source: ERG, 2017.

Figure 8-1. Breakdown of AMS Acceptance Submittal Performance Data Scores

It is important to note that EPA's AMS performance data quality assessment did not evaluate the actual performance of the tested BWMS. EPA determined such an assessment was inappropriate, as the quality of the data packages were insufficient to demonstrate that the represented performance could be consistently achieved under operational conditions onboard vessels. However, the MEPC and the American Bureau of Shipping (ABS) have recently conducted studies of BWMS performance (MEPC, 2015 and ABS, 2017).

An IMO report (MEPC, 2015) on the implementation of the G8 standards concluded that, due to divergent interpretation of G8, differences exist in how BWMS testing is carried out and how type approval is granted. Furthermore, a lack of publicly available documentation on processes and verification hinders transparency and confidence in the testing and approval regime. Based on data from 122 ships with BWMS, the study also found that BWMS appear to be irregularly operated and monitored, restricting the ability to evaluate overall BWMS performance. Reported technical and mechanical malfunctions included sensors/controls, piping/valve systems, and problems associated with filtration. Very few assessments of biological performance have been conducted to determine if BWMS are meeting the D-2 performance standards (MEPC, 2015).

ABS recently assessed the operational performance of BWMS onboard vessels (ABS, 2017). ABS conducted ballast water management workshops in Greece and the US for ship owners with BWMS installed onboard their vessels. Workshop participants completed questionnaires, providing information on installation, commissioning, crew training, in-operation experience, after sale service, and post operation experience and challenges. ABS's analysis of questionnaires responses and other aggregated information on 220 BMWS found that 43 percent

of systems were either inoperable (14 percent) or considered problematic (29 percent). Regarding the remaining 57 percent, 14 percent were reported as being regularly operated and subject to monitoring and/or efficacy testing, and 43 percent were operating but were not subject to monitoring or efficacy testing to date. Ship owners described both operational incidents (hardware failure, software failure, and data logging issues) and maintenance incidents (operation and maintenance manual issues, spare parts issues, and maintenance events). Recurring issues included:

- Hardware maintenance and maintaining appropriate spare parts.
- Software updates and malfunctions.
- Total residual oxidant (TRO) and oxygen sensor calibration (continuous recalibration of sensor that will not stay in calibration and calibration failure).
- Proper storage and handling of consumable chemicals, including TRO measurement reagents (managing shelf life and restocking schedules).
- Reduced UV lamp life (likely caused by cooling water interruptions and frequent start up and shut down reducing operating life).
- Filter clogging and cleaning in muddy/turbid waters (reduced ballast water throughput).
- Proper crew training on operational procedures and maintenance schedules for variety of BWMS operated on rotation.
- Insufficient vendor after-service networks and support (ABS, 2017).

8.5 USCG TYPE APPROVAL PERFORMANCE REVIEW

EPA contacted vendors whose BWMS have received USCG type approval certificates to request performance testing data. EPA did not request or independently review Test Reports and other performance testing documentation for performance and data quality. Instead, EPA relied upon the approval procedures at 40 CFR §162.060-10 as sufficient to ensure data quality. EPA determined that performance data developed in accordance with the procedures and requirements provided at 46 CFR part 162 represent a quality rating system score of 5 (see Table 8-1) and therefore are of sufficient quality for use in evaluating BWMS performance. See Sections 8.1 and 2.3.5 for additional discussion of the USCG type approval process.

To date, EPA has received performance test data from 2 vendors. Performance test data from Alfa Laval are summarized in Table 8-2. These data show that the Alfa Laval's PureBallast 3 BWMS achieved the 2013 VGP ballast water discharge limits (expressed as instantaneous maximum) in marine water, brackish water and freshwater. Concentrations of the regulated microbes in untreated ballast water are generally well below the discharge limits, which limits their utility for evaluating BWMS performance or as an indicator of compliance for other

Table 8-2. Alfa Laval PureBallast 3 Performance Test Data Summary

Test	≥50 µm (organisms/m³)		≥10-<50 µm (organisms/mL)		*E. coli* (cfu/100 mL)		Vibrio cholerae (cfu/100 mL)		Enterococci (cfu/100 mL)	
	Influent	**Discharge**	**Influent**	**Discharge**	**Influent**	**Discharge**	**Influent**	**Discharge**	**Influent**	**Discharge**
Land-Based Tests – Brackish Water										
Brackish Test 1	227,313	0.0	1,780	1.70	12	<10	Absent	Absent	<10	<10
Brackish Test 2	385,076	1.0	1,364	1.60	160	<10	Absent	Absent	26	<10
Brackish Test 3	238,329	1.0	2,486	0.11	<10	<10	Absent	Absent	17	<10
Brackish Test 4	337,933	0.0	1,044	0.78	<10	<10	Absent	Absent	<10	<10
Brackish Test 5	337,933	0.0	1,044	0.22	<10	<10	Absent	Absent	<10	<10
Average	**305,317**	**0.4**	**1,544**	**0.88**	**86**	**<10**	**Absent**	**Absent**	**22**	**<10**
Discharge Limit		<10		<10		<250		<1		<100
Land-Based Tests – Marine Water										
Marine Test 1	262,903	0.00	3,264	0.89	<10	<10	Absent	Absent	17	<10
Marine Test 2	214,325	0.33	2,956	0.56	26	<10	Absent	Absent	19	<10
Marine Test 3	214,325	0.00	2,956	0.33	26	<10	Absent	Absent	19	<10
Marine Test 4	314,435	2.70	1,078	3.70	213	<10	Absent	Absent	104	<10
Marine Test 5	314,435	1.30	1,078	2.20	213	<10	Absent	Absent	104	<10
Average	**264,085**	**0.87**	**2,266**	**1.54**	**120**	**<10**	**Absent**	**Absent**	**53**	**<10**
Discharge Limit		<10		<10		<250		<1		<100
Land-Based Tests – Freshwater										
Freshwater 1	632,347	0.00	1,779	3.90	6	<1.0	Absent	Absent	3	<1.0
Freshwater 1	555,446	0.33	3,012	0.44	62	<1.0	Absent	Absent	183	<1.0
Freshwater 1	555,446	0.00	3,012	0.89	62	<1.0	Absent	Absent	183	<1.0
Freshwater 1	425,060	0.00	2,244	0.67	387	<1.0	Absent	Absent	155	<1.0
Freshwater 1	425,060	1.00	2,244	0.67	387	<1.0	Absent	Absent	155	<1.0
Average	**518,672**	**0.27**	**2,458**	**1.31**	**181**	**<1.0**	**Absent**	**Absent**	**136**	**<1.0**
Discharge Limit		<10		<10		<250		<1		<100
Shipboard Tests										
Shipboard 1	8,490	0.0	1,102	2.8	<10	11	Absent	Absent	<10	<10
Shipboard 2	2,100	0.0	787	0.8	<10	<10	Absent	Absent	<10	<10
Shipboard 3	23,603	1.9	103	0.7	14	<10	Absent	Absent	<10	<10
Shipboard 4	10,665	7.0	175	6.4	69	<10	Absent	Absent	32	<10
Shipboard 5	20,272	4.6	128	0.2	<10	<10	Absent	Absent	<10	<10
Average	**13,026**	**3**	**459**	**2**	**42**	**11**	**Absent**	**Absent**	**32**	**<10**
Discharge Limit		<10		<10		<250		<1		<100

Source: Alfa Laval, 2017.

regulated biological/size categories; these results are consistent with findings of BWMS testing by test facilities around the world (Tamburri, 2017).

Test data submitted by the second vendor included a claim of confidential business information and are not summarized in this report.

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